

US009222626B1

(12) **United States Patent**
Timmermans et al.

(10) **Patent No.:** **US 9,222,626 B1**
(45) **Date of Patent:** ***Dec. 29, 2015**

(54) **LIGHT TUBE AND POWER SUPPLY CIRCUIT**

(71) Applicant: **iLumisys, Inc.**, Troy, MI (US)

(72) Inventors: **Jos Timmermans**, Ortonville, MI (US);
Jean C. Raymond, Nominique (CA);
John Ivey, Farmington Hills, MI (US)

(73) Assignee: **ILUMISYS, INC.**, Troy, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/669,963**

(22) Filed: **Mar. 26, 2015**

Related U.S. Application Data

(63) Continuation of application No. 14/299,909, filed on Jun. 9, 2014, now Pat. No. 9,006,990, and a continuation of application No. 14/299,915, filed on Jun. 9, 2014, now Pat. No. 9,006,993, said application

(Continued)

(51) **Int. Cl.**

F21S 4/00 (2006.01)

F21K 99/00 (2010.01)

H05B 33/08 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC **F21K 9/175** (2013.01); **F21V 23/009** (2013.01); **H05B 33/0815** (2013.01); **H05B 33/0845** (2013.01); **F21Y 2103/003** (2013.01)

(58) **Field of Classification Search**

USPC 362/249.01, 249.02, 260, 285, 185 R, 362/185 S, 312, 246

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

D84,763 S 7/1931 Strange
D119,797 S 4/1940 Winkler et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE 29900320 U1 5/1995
DE 196 51 140 A1 6/1997

(Continued)

OTHER PUBLICATIONS

Defendant's Invalidation Contentions in *Altair Engineering, Inc. v. LEDS America, Inc.*, Civil Case No. 2:10-CV-13424 (E. D. Mich.)(J. O'Meara)(Feb. 4, 2011).

(Continued)

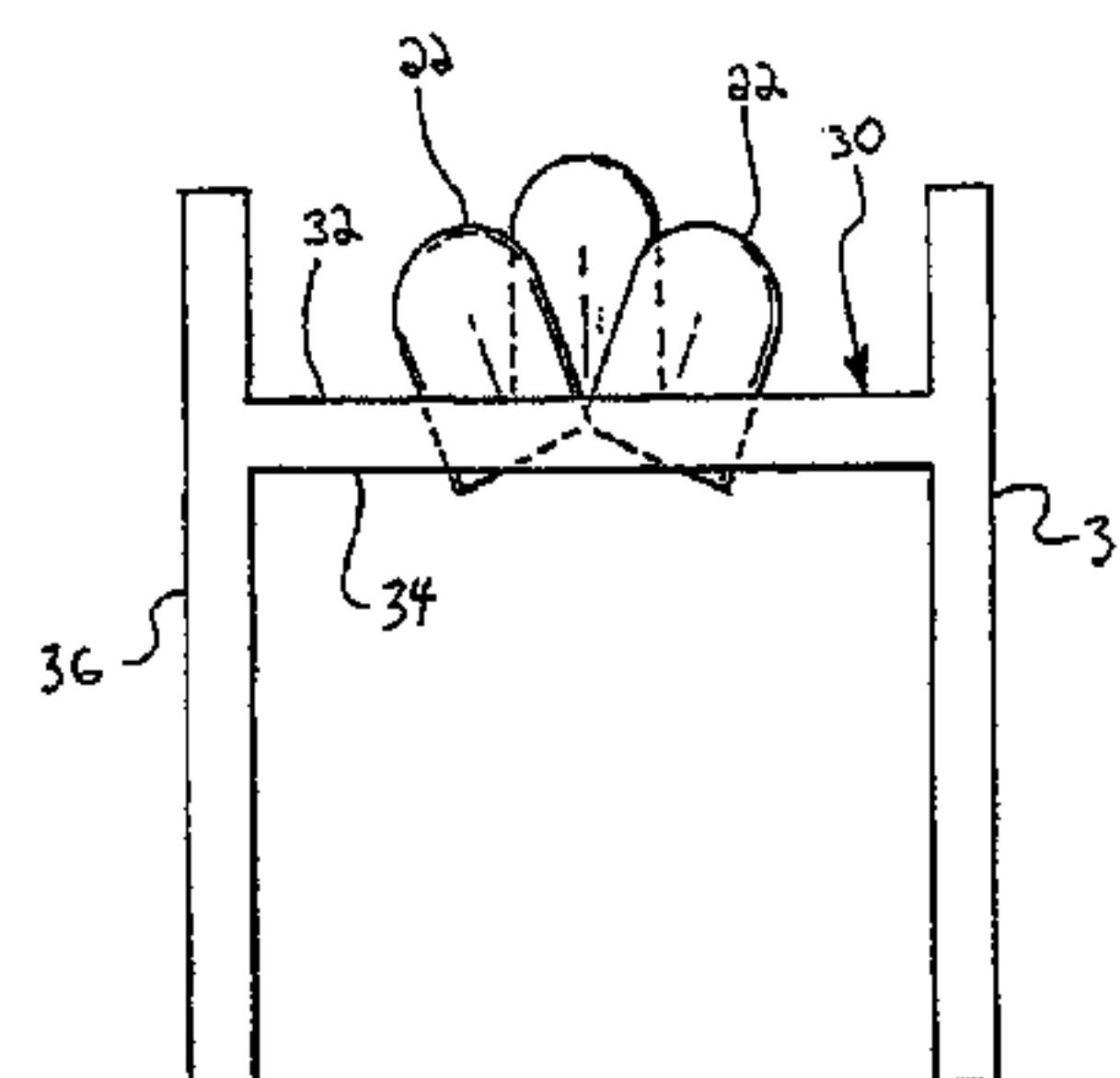
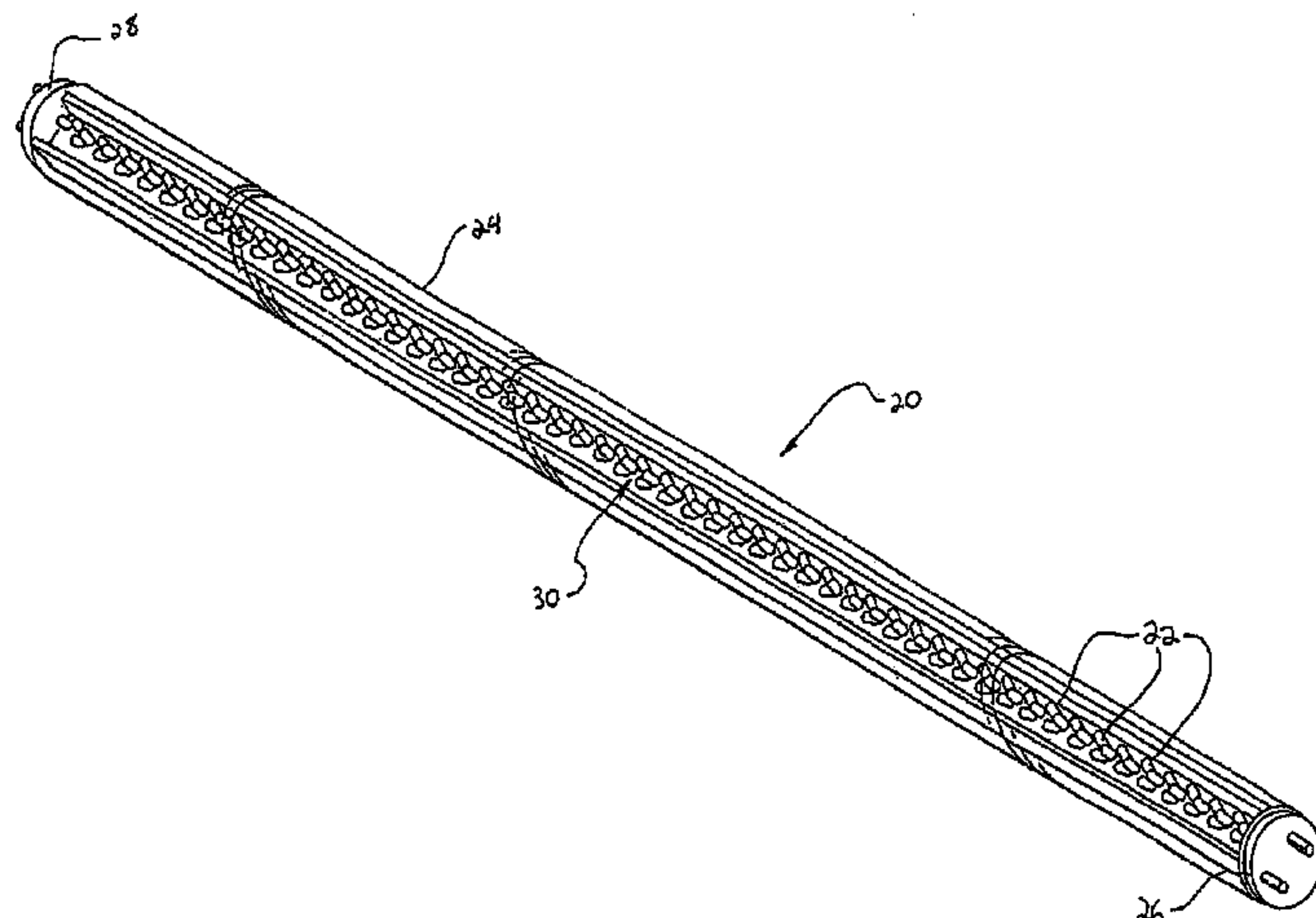
Primary Examiner — Minh D A

(74) *Attorney, Agent, or Firm* — Young, Basile, Hanlon & Macfarlane, P.C.

(57) **ABSTRACT**

A replacement light tube for replacing a fluorescent light tube includes an elongate tubular housing having first and second ends, first and second end caps disposed thereon, each configured to fit with a socket for the fluorescent light tube, and a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first and second ends and having spaced-apart sidewalls extending away from the first surface and extending within the housing between the first and second ends. At least a portion of the sidewalls are in contact with an interior surface of housing. A plurality of white light emitting diodes are supported only by a second surface of the planar portion opposite to the first surface and between the first and second ends, and are arranged to emit light through the housing.

30 Claims, 9 Drawing Sheets



Related U.S. Application Data

No. 14/299,909 is a continuation of application No. 13/777,331, filed on Feb. 26, 2013, now Pat. No. 8,866,396, said application No. 14/299,915 is a continuation of application No. 13/777,331, which is a continuation of application No. 12/965,019, filed on Dec. 10, 2010, now Pat. No. 8,382,327, which is a continuation of application No. 11/085,744, filed on Mar. 21, 2005, now Pat. No. 8,247,985, which is a continuation of application No. 09/782,375, filed on Feb. 12, 2001, now Pat. No. 7,049,761.

(60) Provisional application No. 60/181,744, filed on Feb. 11, 2000.

(51) **Int. Cl.**

F21V 23/00 (2015.01)

F21Y 103/00 (2006.01)

(56)

References Cited

U.S. PATENT DOCUMENTS

D125,312 S	2/1941	Logan	4,394,719 A	7/1983	Moberg
2,826,679 A	3/1958	Rosenberg	4,420,711 A	12/1983	Takahashi et al.
2,909,097 A	10/1959	Alden et al.	4,455,562 A	6/1984	Dolan et al.
3,178,622 A	4/1965	Paul et al.	4,500,796 A	2/1985	Quin
3,272,977 A	9/1966	Holmes	4,521,835 A	6/1985	Meggs et al.
3,318,185 A	5/1967	Kott	4,531,114 A	7/1985	Topol et al.
3,561,719 A	2/1971	Grindle	4,581,687 A	4/1986	Nakanishi
3,586,936 A	6/1971	McLeroy	4,597,033 A	6/1986	Meggs et al.
3,601,621 A	8/1971	Ritchie	4,600,972 A	7/1986	MacIntyre
3,612,855 A	10/1971	Juhnke	4,607,317 A	8/1986	Lin
3,643,088 A	2/1972	Osteen et al.	4,622,881 A	11/1986	Rand
3,739,336 A	6/1973	Burland	4,625,152 A	11/1986	Nakai
3,746,918 A	7/1973	Drucker et al.	4,635,052 A	1/1987	Aoike et al.
3,818,216 A	6/1974	Larraburu	4,647,217 A	3/1987	Havel
3,821,590 A	6/1974	Kosman et al.	4,650,971 A	3/1987	Manecci et al.
3,832,503 A	8/1974	Crane	4,656,398 A	4/1987	Michael et al.
3,858,086 A	12/1974	Anderson et al.	4,661,890 A	4/1987	Watanabe et al.
3,909,670 A	9/1975	Wakamatsu et al.	4,668,895 A	5/1987	Schneiter
3,924,120 A	12/1975	Cox, III	4,669,033 A	5/1987	Lee
3,958,885 A	5/1976	Stockinger et al.	4,675,575 A	6/1987	Smith et al.
3,969,720 A	7/1976	Nishino	4,682,079 A	7/1987	Sanders et al.
3,974,637 A	8/1976	Bergey et al.	4,686,425 A	8/1987	Havel
3,993,386 A	11/1976	Rowe	4,687,340 A	8/1987	Havel
4,001,571 A	1/1977	Martin	4,688,154 A	8/1987	Nilssen
4,009,394 A	2/1977	Mierzwinski	4,688,869 A	8/1987	Kelly
4,054,814 A	10/1977	Fegley et al.	4,695,769 A	9/1987	Schweickardt
4,070,568 A	1/1978	Gala	4,698,730 A	10/1987	Sakai et al.
4,082,395 A	4/1978	Donato et al.	4,701,669 A	10/1987	Head et al.
4,096,349 A	6/1978	Donato	4,705,406 A	11/1987	Havel
4,102,558 A	7/1978	Krachman	4,707,141 A	11/1987	Havel
4,107,581 A	8/1978	Abernethy	D293,723 S	1/1988	Buttner
4,189,663 A	2/1980	Schmutzer et al.	4,727,289 A	2/1988	Uchida
4,211,955 A	7/1980	Ray	4,727,457 A	2/1988	Thillays
4,241,295 A	12/1980	Williams, Jr.	4,739,454 A	4/1988	Federgreen
4,257,672 A	3/1981	Balliet	4,740,882 A	4/1988	Miller
4,261,029 A	4/1981	Mousset	4,748,545 A	5/1988	Schmitt
4,262,255 A	4/1981	Kokei et al.	4,753,148 A	6/1988	Johnson
4,271,408 A	6/1981	Teshima et al.	4,758,173 A	7/1988	Northrop
4,271,458 A	6/1981	George, Jr.	4,765,708 A	8/1988	Becker et al.
4,272,689 A	6/1981	Crosby et al.	4,767,172 A	8/1988	Nichols et al.
4,273,999 A	6/1981	Pierpoint	4,771,274 A	9/1988	Havel
4,298,869 A	11/1981	Okuno	4,780,621 A	10/1988	Bartleucci et al.
4,329,625 A	5/1982	Nishizawa et al.	4,794,373 A	12/1988	Harrison
4,339,788 A	7/1982	White et al.	4,794,383 A	12/1988	Havel
4,342,947 A	8/1982	Bloyd	4,801,928 A	1/1989	Minter
4,344,117 A	8/1982	Niccum	4,810,937 A	3/1989	Havel
4,367,464 A	1/1983	Kurahashi et al.	4,818,072 A	4/1989	Mohebban
D268,134 S	3/1983	Zurcher	4,824,269 A	4/1989	Havel
4,382,272 A	5/1983	Quella et al.	4,837,565 A	6/1989	White
4,388,567 A	6/1983	Yamazaki et al.	4,843,627 A	6/1989	Stebbins
4,388,589 A	6/1983	Molldrem, Jr.	4,845,481 A	7/1989	Havel
4,392,187 A	7/1983	Bornhorst	4,845,745 A	7/1989	Havel
			4,847,536 A	7/1989	Lowe et al.
			4,851,972 A	7/1989	Altman
			4,854,701 A	8/1989	Noll et al.
			4,857,801 A	8/1989	Farrell
			4,863,223 A	9/1989	Weissenbach et al.
			4,870,325 A	9/1989	Kazar
			4,874,320 A	10/1989	Freed et al.
			4,887,074 A	12/1989	Simon et al.
			4,894,832 A	1/1990	Colak
			4,901,207 A	2/1990	Sato et al.
			4,904,988 A	2/1990	Nesbit et al.
			4,912,371 A	3/1990	Hamilton
			4,920,459 A	4/1990	Rothwell et al.
			4,922,154 A	5/1990	Cacoub
			4,929,936 A	5/1990	Friedman et al.
			4,934,852 A	6/1990	Havel
			4,941,072 A	7/1990	Yasumoto et al.
			4,943,900 A	7/1990	Gartner
			4,962,687 A	10/1990	Belliveau et al.
			4,965,561 A	10/1990	Havel
			4,973,835 A	11/1990	Kurosu et al.
			4,977,351 A	12/1990	Bavaro et al.
			4,979,081 A	12/1990	Leach et al.
			4,979,180 A	12/1990	Muncheryan
			4,980,806 A	12/1990	Taylor et al.
			4,991,070 A	2/1991	Stob
			4,992,704 A	2/1991	Stinson

(56)

References Cited

U.S. PATENT DOCUMENTS

5,001,609 A	3/1991	Gardner et al.	5,432,408 A	7/1995	Matsuda et al.
5,003,227 A	3/1991	Nilssen	5,436,535 A	7/1995	Yang
5,008,595 A	4/1991	Kazar	5,436,853 A	7/1995	Shimohara
5,008,788 A	4/1991	Palinkas	5,450,301 A	9/1995	Waltz et al.
5,010,459 A	4/1991	Taylor et al.	5,461,188 A	10/1995	Drago et al.
5,018,054 A	5/1991	Ohashi et al.	5,463,280 A	10/1995	Johnson
5,027,037 A	6/1991	Wei	5,463,502 A	10/1995	Savage, Jr.
5,027,262 A	6/1991	Freed	5,465,144 A	11/1995	Parker et al.
5,032,960 A	7/1991	Kato	5,473,522 A	12/1995	Kriz et al.
5,034,807 A	7/1991	Von Kohorn	5,475,300 A	12/1995	Havel
5,036,248 A	7/1991	McEwan et al.	5,481,441 A	1/1996	Stevens
5,038,255 A	8/1991	Nishihashi et al.	5,489,827 A	2/1996	Xia
5,065,226 A	11/1991	Kluitmans et al.	5,491,402 A	2/1996	Small
5,072,216 A	12/1991	Grange	5,493,183 A	2/1996	Kimball
5,078,039 A	1/1992	Tulk et al.	5,504,395 A	4/1996	Johnson et al.
5,083,063 A	1/1992	Brooks	5,506,760 A	4/1996	Giebler et al.
5,088,013 A	2/1992	Revis	5,513,082 A	4/1996	Asano
5,089,748 A	2/1992	Ihms	5,519,496 A	5/1996	Borgert et al.
5,103,382 A	4/1992	Kondo et al.	5,530,322 A	6/1996	Ference et al.
5,122,733 A	6/1992	Havel	5,539,628 A	7/1996	Seib
5,126,634 A	6/1992	Johnson	5,544,809 A	8/1996	Keating et al.
5,128,595 A	7/1992	Hara	5,545,950 A	8/1996	Cho
5,130,761 A	7/1992	Tanaka	5,550,440 A	8/1996	Allison et al.
5,130,909 A	7/1992	Gross	5,559,681 A	9/1996	Duarte
5,134,387 A	7/1992	Smith et al.	5,561,346 A	10/1996	Byrne
5,136,483 A	8/1992	Schoniger et al.	D376,030 S	11/1996	Cohen
5,140,220 A	8/1992	Hasegawa	5,575,459 A	11/1996	Anderson
5,142,199 A	8/1992	Elwell	5,575,554 A	11/1996	Guritz
5,151,679 A	9/1992	Dimmick	5,581,158 A	12/1996	Quazi
5,154,641 A	10/1992	McLaughlin	5,592,051 A	1/1997	Korkala
5,161,879 A	11/1992	McDermott	5,592,054 A	1/1997	Nerone et al.
5,161,882 A	11/1992	Garrett	5,600,199 A	2/1997	Martin, Sr. et al.
5,164,715 A	11/1992	Kashiwabara et al.	5,607,227 A	3/1997	Yasumoto et al.
5,184,114 A	2/1993	Brown	5,608,290 A	3/1997	Hutchisson et al.
5,194,854 A	3/1993	Havel	5,614,788 A	3/1997	Mullins et al.
5,198,756 A	3/1993	Jenkins et al.	5,621,282 A	4/1997	Haskell
5,209,560 A	5/1993	Taylor et al.	5,621,603 A	4/1997	Adamec et al.
5,220,250 A	6/1993	Szuba	5,621,662 A	4/1997	Humphries et al.
5,225,765 A	7/1993	Callahan et al.	5,622,423 A	4/1997	Lee
5,226,723 A	7/1993	Chen	5,633,629 A	5/1997	Hochstein
5,254,910 A	10/1993	Yang	5,634,711 A	6/1997	Kennedy et al.
5,256,948 A	10/1993	Boldin et al.	5,639,158 A	6/1997	Sato
5,268,828 A	12/1993	Miura	5,640,061 A	6/1997	Bornhorst et al.
5,278,542 A	1/1994	Smith et al.	5,640,141 A	6/1997	Myllymaki
5,282,121 A	1/1994	Bornhorst et al.	5,640,792 A	6/1997	O'Shea et al.
5,283,517 A	2/1994	Havel	5,642,129 A	6/1997	Zavracky et al.
5,287,352 A	2/1994	Jackson et al.	5,655,830 A *	8/1997	Ruskouski F21K 9/135 257/E25.028
5,294,865 A	3/1994	Haraden	5,656,935 A	8/1997	Havel
5,298,871 A	3/1994	Shimohara	5,661,374 A	8/1997	Cassidy et al.
5,301,090 A	4/1994	Hed	5,661,645 A	8/1997	Hochstein
5,303,124 A	4/1994	Wrobel	5,673,059 A	9/1997	Zavracky et al.
5,307,295 A	4/1994	Taylor et al.	5,682,103 A	10/1997	Burrell
5,321,593 A	6/1994	Moates	5,684,523 A	11/1997	Satoh et al.
5,323,226 A	6/1994	Schreder	5,688,042 A	11/1997	Madadi et al.
5,329,431 A	7/1994	Taylor et al.	5,690,417 A	11/1997	Choate et al.
5,344,068 A	9/1994	Haessig	5,697,695 A	12/1997	Lin et al.
5,350,977 A	9/1994	Hamamoto et al.	5,701,058 A	12/1997	Roth
5,357,170 A	10/1994	Luchaco et al.	5,712,650 A	1/1998	Barlow
5,365,411 A	11/1994	Rycroft et al.	5,713,655 A	2/1998	Blackman
5,371,618 A	12/1994	Tai et al.	5,721,471 A	2/1998	Begemann et al.
5,374,876 A	12/1994	Horibata et al.	5,725,148 A	3/1998	Hartman
5,375,043 A	12/1994	Tokunaga	5,726,535 A	3/1998	Yan
D354,360 S	1/1995	Murata	5,731,759 A	3/1998	Finucan
5,381,074 A	1/1995	Rudzewicz et al.	5,734,590 A	3/1998	Tebbe
5,388,357 A	2/1995	Malita	5,751,118 A	5/1998	Mortimer
5,402,702 A	4/1995	Hata	5,752,766 A	5/1998	Bailey et al.
5,404,094 A	4/1995	Green et al.	5,765,940 A	6/1998	Levy et al.
5,404,282 A	4/1995	Klinke et al.	5,769,527 A	6/1998	Taylor et al.
5,406,176 A	4/1995	Sugden	5,784,006 A	7/1998	Hochstein
5,410,328 A	4/1995	Yoksza et al.	5,785,227 A	7/1998	Akiba
5,412,284 A	5/1995	Moore et al.	5,790,329 A	8/1998	Klaus et al.
5,412,552 A	5/1995	Fernandes	5,803,579 A	9/1998	Turnbull et al.
5,420,482 A	5/1995	Phares	5,803,580 A	9/1998	Tseng
5,421,059 A	6/1995	Leffers, Jr.	5,803,729 A	9/1998	Tsimerman
5,430,356 A	7/1995	Ference et al.	5,806,965 A	9/1998	Deese
			5,808,689 A	9/1998	Small
			5,810,463 A	9/1998	Kawahara et al.
			5,812,105 A	9/1998	Van de Ven

(56)

References Cited

U.S. PATENT DOCUMENTS

5,813,751 A	9/1998	Shaffer	6,127,783 A	10/2000	Pashley et al.
5,813,753 A	9/1998	Vriens et al.	6,132,072 A	10/2000	Turnbull et al.
5,821,695 A	10/1998	Vilanilam et al.	6,135,604 A	10/2000	Lin
5,825,051 A	10/1998	Bauer et al.	6,135,620 A	10/2000	Marsh
5,828,178 A	10/1998	York et al.	6,139,174 A	10/2000	Butterworth
5,831,522 A	11/1998	Weed et al.	6,149,283 A	11/2000	Conway et al.
5,836,676 A	11/1998	Ando et al.	6,150,774 A	11/2000	Mueller et al.
5,848,837 A	12/1998	Gustafson	6,151,529 A	11/2000	Batko
5,850,126 A	12/1998	Kanbar	6,153,985 A	11/2000	Grossman
5,851,063 A	12/1998	Doughty et al.	6,158,882 A	12/2000	Bischoff, Jr.
5,852,658 A	12/1998	Knight et al.	6,166,496 A	12/2000	Lys et al.
5,854,542 A	12/1998	Forbes	6,175,201 B1	1/2001	Sid
RE36,030 E	1/1999	Nadeau	6,175,220 B1	1/2001	Billig et al.
5,859,508 A	1/1999	Ge et al.	6,181,126 B1	1/2001	Havel
5,865,529 A	2/1999	Yan	D437,947 S	2/2001	Huang
5,870,233 A	2/1999	Benz et al.	6,183,086 B1	2/2001	Neubert
5,890,794 A	4/1999	Abtahi et al.	6,183,104 B1	2/2001	Ferrara
5,893,633 A	4/1999	Saito et al.	6,184,628 B1	2/2001	Ruthenberg
5,896,010 A	4/1999	Mikolajczak et al.	6,196,471 B1	3/2001	Ruthenberg
5,904,415 A	5/1999	Robertson et al.	6,203,180 B1	3/2001	Fleischmann
5,907,742 A	5/1999	Johnson et al.	6,211,626 B1	4/2001	Lys et al.
5,909,378 A	6/1999	De Milleville	6,215,409 B1	4/2001	Blach
5,912,653 A	6/1999	Fitch	6,217,190 B1	4/2001	Altman et al.
5,917,287 A	6/1999	Haederle et al.	6,219,239 B1	4/2001	Mellberg et al.
5,917,534 A	6/1999	Rajeswaran	6,227,679 B1	5/2001	Zhang et al.
5,921,660 A	7/1999	Yu	6,234,645 B1	5/2001	Börner et al.
5,924,784 A	7/1999	Chliwnyj et al.	6,238,075 B1	5/2001	Dealey, Jr. et al.
5,927,845 A	7/1999	Gustafson et al.	6,240,665 B1	6/2001	Brown et al.
5,934,792 A	8/1999	Camarota	6,241,359 B1	6/2001	Lin
5,936,599 A	8/1999	Reymond	6,249,221 B1	6/2001	Reed
5,943,802 A	8/1999	Tijanac	6,250,774 B1	6/2001	Begemann et al.
5,946,209 A	8/1999	Eckel et al.	6,252,350 B1	6/2001	Alvarez
5,949,347 A *	9/1999	Wu 340/815.45	6,252,358 B1	6/2001	Xydis et al.
5,951,145 A	9/1999	Iwasaki et al.	6,268,600 B1	7/2001	Nakamura et al.
5,952,680 A	9/1999	Strite	6,273,338 B1	8/2001	White
5,959,547 A	9/1999	Tubel et al.	6,292,901 B1	9/2001	Lys et al.
5,961,072 A	10/1999	Bodle	6,297,724 B1	10/2001	Bryans et al.
5,962,989 A	10/1999	Baker	6,305,109 B1	10/2001	Lee
5,962,992 A	10/1999	Huang et al.	6,305,821 B1	10/2001	Hsieh et al.
5,963,185 A	10/1999	Havel	6,307,331 B1	10/2001	Bonasia et al.
5,966,069 A	10/1999	Zmurk et al.	6,310,590 B1	10/2001	Havel
5,974,553 A	10/1999	Gandar	6,315,429 B1	11/2001	Grandolfo
5,980,064 A	11/1999	Metroyanis	6,323,832 B1	11/2001	Nishizawa et al.
5,998,925 A	12/1999	Shimizu et al.	6,325,651 B1	12/2001	Nishihara et al.
5,998,928 A	12/1999	Hipp	6,334,699 B1	1/2002	Gladnick
6,000,807 A	12/1999	Moreland	6,340,868 B1	1/2002	Lys et al.
6,007,209 A	12/1999	Pelka	6,362,578 B1	3/2002	Swanson et al.
6,008,783 A	12/1999	Kitagawa et al.	6,371,637 B1	4/2002	Atchinson et al.
6,010,228 A	1/2000	Blackman et al.	6,380,865 B1	4/2002	Pederson
6,011,691 A	1/2000	Schreffler	6,394,623 B1	5/2002	Tsui
6,016,038 A	1/2000	Mueller et al.	6,400,096 B1	6/2002	Wells et al.
6,018,237 A	1/2000	Havel	6,404,131 B1	6/2002	Kawano et al.
6,019,493 A	2/2000	Kuo et al.	6,411,045 B1	6/2002	Nerone
6,020,825 A	2/2000	Chansky et al.	6,429,604 B1	8/2002	Chang
6,025,550 A	2/2000	Kato	6,445,139 B1	9/2002	Marshall et al.
6,028,694 A	2/2000	Schmidt	6,459,919 B1	10/2002	Lys et al.
6,030,099 A	2/2000	McDermott	6,464,373 B1	10/2002	Petrick
6,031,343 A	2/2000	Recknagel et al.	6,469,457 B2	10/2002	Callahan
6,031,958 A	2/2000	McGaffigan	6,471,388 B1	10/2002	Marsh
6,036,335 A	3/2000	Openiano	6,495,964 B1	12/2002	Muthu et al.
6,036,336 A	3/2000	Wu	6,511,204 B2	1/2003	Emmel et al.
D422,737 S	4/2000	Orozco	6,528,954 B1	3/2003	Lys et al.
6,056,420 A	5/2000	Wilson et al.	6,540,381 B1	4/2003	Douglass, II
6,068,383 A	5/2000	Robertson et al.	6,541,800 B2	4/2003	Barnett et al.
6,069,597 A	5/2000	Hansen	6,548,967 B1	4/2003	Dowling et al.
6,072,280 A	6/2000	Allen	6,568,834 B1	5/2003	Scianna
6,084,359 A	7/2000	Hetzl et al.	6,577,072 B2	6/2003	Saito et al.
6,086,220 A	7/2000	Lash et al.	6,577,080 B2	6/2003	Lys et al.
6,091,200 A	7/2000	Lenz	6,577,794 B1	6/2003	Currie et al.
6,092,915 A	7/2000	Rensch	6,582,103 B1	6/2003	Popovich et al.
6,095,661 A	8/2000	Lebens et al.	6,585,393 B1	7/2003	Brandes et al.
6,097,352 A	8/2000	Zavracky et al.	6,608,453 B2	8/2003	Morgan et al.
6,115,184 A	9/2000	Hubble, III et al.	6,609,813 B1	8/2003	Showers et al.
6,116,748 A	9/2000	George	6,612,729 B1	9/2003	Hoffman
6,121,875 A	9/2000	Hamm et al.	6,621,222 B1	9/2003	Hong
			6,624,597 B2	9/2003	Dowling et al.
			6,682,205 B2	1/2004	Lin
			6,712,486 B1	3/2004	Popovich et al.
			6,717,376 B2	4/2004	Lys et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,720,745 B2 4/2004 Lys et al.
 6,736,525 B2 5/2004 Chin
 6,762,562 B2 7/2004 Leong
 6,768,047 B2 7/2004 Chang et al.
 6,774,584 B2 8/2004 Lys et al.
 6,777,891 B2 8/2004 Lys et al.
 6,781,329 B2 8/2004 Mueller et al.
 6,788,011 B2 9/2004 Mueller et al.
 6,796,680 B1 9/2004 Showers et al.
 6,806,659 B1 10/2004 Mueller et al.
 6,853,151 B2 2/2005 Leong et al.
 6,869,204 B2 3/2005 Morgan et al.
 6,888,322 B2 5/2005 Dowling et al.
 6,897,624 B2 5/2005 Lys et al.
 6,936,978 B2 8/2005 Morgan et al.
 6,953,261 B1 10/2005 Jiao et al.
 6,965,205 B2 11/2005 Piepgras et al.
 6,967,448 B2 11/2005 Morgan et al.
 6,975,079 B2 12/2005 Lys et al.
 7,014,336 B1 3/2006 Ducharme et al.
 7,031,920 B2 4/2006 Dowling et al.
 7,038,398 B1 5/2006 Lys et al.
 7,049,761 B2 5/2006 Timmermans et al.
 7,064,498 B2 6/2006 Dowling et al.
 7,102,902 B1 9/2006 Brown et al.
 7,113,541 B1 9/2006 Lys et al.
 7,120,560 B2 10/2006 Williams et al.
 7,132,785 B2 11/2006 Ducharme
 7,132,804 B2 11/2006 Lys et al.
 7,135,824 B2 11/2006 Lys et al.
 7,139,617 B1 11/2006 Morgan et al.
 7,161,311 B2 1/2007 Mueller et al.
 7,161,313 B2 1/2007 Piepgras et al.
 7,180,252 B2 2/2007 Lys et al.
 7,186,003 B2 3/2007 Dowling et al.
 7,187,141 B2 3/2007 Mueller et al.
 7,221,104 B2 5/2007 Lys et al.
 7,231,060 B2 6/2007 Dowling et al.
 7,233,831 B2 6/2007 Blackwell
 7,242,152 B2 7/2007 Dowling et al.
 7,248,239 B2 7/2007 Dowling et al.
 7,253,566 B2 8/2007 Lys et al.
 7,255,457 B2 8/2007 Ducharme et al.
 7,274,160 B2 9/2007 Mueller et al.
 7,308,296 B2 12/2007 Lys et al.
 7,309,965 B2 12/2007 Dowling et al.
 7,344,278 B2 3/2008 Paravantsos
 7,350,936 B2 4/2008 Ducharme et al.
 7,353,071 B2 4/2008 Blackwell et al.
 7,385,359 B2 6/2008 Dowling et al.
 7,401,935 B2 7/2008 VanderSchuit
 7,427,840 B2 9/2008 Morgan et al.
 7,510,299 B2 3/2009 Timmermans et al.
 7,598,686 B2 10/2009 Lys et al.
 7,600,907 B2 10/2009 Liu et al.
 RE42,161 E 2/2011 Hochstein
 8,093,823 B1 1/2012 Ivey et al.
 8,247,985 B2 8/2012 Timmermans et al.
 8,382,327 B2 2/2013 Timmermans et al.
 8,482,212 B1 7/2013 Ivey et al.
 8,870,412 B1* 10/2014 Timmermans F21K 9/17
 362/249.01

2002/0130627 A1 9/2002 Morgan et al.
 2002/0152045 A1 10/2002 Dowling et al.
 2002/0153851 A1 10/2002 Morgan et al.
 2002/0158583 A1 10/2002 Lys et al.
 2002/0163316 A1 11/2002 Lys et al.
 2002/0171365 A1 11/2002 Morgan et al.
 2002/0171377 A1 11/2002 Mueller et al.
 2002/0171378 A1 11/2002 Morgan et al.
 2002/0176259 A1 11/2002 Ducharme
 2003/0011538 A1 1/2003 Lys et al.
 2003/0057884 A1 3/2003 Dowling et al.
 2003/0057886 A1 3/2003 Lys et al.
 2003/0057887 A1 3/2003 Dowling et al.
 2003/0057890 A1 3/2003 Lys et al.
 2003/0076281 A1 4/2003 Morgan et al.
 2003/0100837 A1 5/2003 Lys et al.
 2003/0133292 A1 7/2003 Mueller et al.
 2003/0137258 A1 7/2003 Piepgras et al.
 2003/0222587 A1 12/2003 Dowling, Jr. et al.
 2004/0052076 A1 3/2004 Mueller et al.
 2004/0085219 A1 5/2004 Pederson
 2004/0090191 A1 5/2004 Mueller et al.
 2004/0105261 A1 6/2004 Ducharme et al.
 2004/0145490 A1 7/2004 Pederson
 2004/0155609 A1 8/2004 Lys et al.
 2004/0178751 A1 9/2004 Mueller et al.
 2004/0212320 A1 10/2004 Dowling et al.
 2004/0212993 A1 10/2004 Morgan et al.
 2004/0240890 A1 12/2004 Lys et al.
 2004/0257007 A1 12/2004 Lys et al.
 2005/0030744 A1 2/2005 Ducharme et al.
 2005/0041161 A1 2/2005 Dowling et al.
 2005/0041424 A1 2/2005 Ducharme
 2005/0043907 A1 2/2005 Eckel et al.
 2005/0044617 A1 3/2005 Mueller et al.
 2005/0047132 A1 3/2005 Dowling et al.
 2005/0047134 A1 3/2005 Mueller et al.
 2005/0062440 A1 3/2005 Lys et al.
 2005/0063194 A1 3/2005 Lys et al.
 2005/0099317 A1 5/2005 Pederson
 2005/0151489 A1 7/2005 Lys et al.
 2005/0166634 A1 8/2005 Lieberman et al.
 2005/0174473 A1 8/2005 Morgan et al.
 2005/0184667 A1 8/2005 Sturman et al.
 2005/0236998 A1 10/2005 Mueller et al.
 2005/0285547 A1 12/2005 Piepgras et al.
 2006/0012987 A9 1/2006 Ducharme et al.
 2006/0016960 A1 1/2006 Morgan et al.
 2006/0050509 A9 3/2006 Dowling et al.
 2006/0109649 A1 5/2006 Ducharme et al.
 2006/0152172 A9 7/2006 Mueller et al.
 2006/0285325 A1 12/2006 Ducharme et al.
 2007/0030683 A1 2/2007 Popovich et al.
 2007/0047227 A1 3/2007 Ducharme
 2007/0086754 A1 4/2007 Lys et al.
 2007/0086912 A1 4/2007 Dowling et al.
 2007/0115658 A1 5/2007 Mueller et al.
 2007/0115665 A1 5/2007 Mueller et al.
 2007/0188427 A1 8/2007 Lys et al.
 2007/0195526 A1 8/2007 Dowling et al.
 2007/0258240 A1 11/2007 Ducharme et al.
 2008/0012506 A1 1/2008 Mueller et al.
 2011/0109454 A1 5/2011 McSheffrey, Sr. et al.
 2013/0200797 A1 8/2013 Timmermans et al.

FOREIGN PATENT DOCUMENTS

2001/0033488 A1 10/2001 Chliwnyj et al.
 2002/0011801 A1 1/2002 Chang
 2002/0047569 A1 4/2002 Dowling et al.
 2002/0047628 A1 4/2002 Morgan et al.
 2002/0048169 A1 4/2002 Dowling et al.
 2002/0048174 A1 4/2002 Pederson
 2002/0057061 A1 5/2002 Mueller et al.
 2002/0070688 A1 6/2002 Dowling et al.
 2002/0074559 A1 6/2002 Dowling et al.
 2002/0074958 A1 6/2002 Crenshaw
 2002/0078221 A1 6/2002 Blackwell et al.
 2002/0101197 A1 8/2002 Lys et al.
 2002/0113555 A1 8/2002 Lys et al.

DE 196 24 087 A1 12/1997
 DE 299 00 320 U1 5/1999
 DE 298 17 609 U1 1/2000
 EP 0 091 172 A2 10/1983
 EP 0 124 924 B1 9/1987
 EP 0 174 699 B1 11/1988
 EP 0 197 602 B1 11/1990
 EP 0 390 262 B1 12/1993
 EP 0 359 329 B1 3/1994
 EP 0 403 011 B1 4/1994
 EP 0 632 511 A2 1/1995
 EP 0 432 848 B1 4/1995

(56)

References Cited

OTHER PUBLICATIONS

FOREIGN PATENT DOCUMENTS

EP	0 525 876	B1	5/1996
EP	0 714 556	B1	1/1999
EP	0 889 283	A1	7/1999
EP	0 458 408	B1	9/1999
EP	0 578 302	B1	9/1999
GB	2165977	A	4/1986
GB	2 215 024	A	9/1989
GB	2 324 901	A	11/1998
JP	S62-241382	A	10/1987
JP	S62-248271	A	10/1987
JP	H05-102530	A	4/1993
JP	H6-54103		7/1994
JP	07-249467	A	9/1995
JP	07-264036	A	10/1995
JP	08-162677	A	6/1996
JP	H8-162677		6/1996
JP	162677	*	8/1996
JP	10-308536	A	11/1998
JP	H11-135274		5/1999
JP	11-162234	A	6/1999
JP	H11-162234	A	6/1999
JP	H11-260125	A	9/1999
JP	5102530	B2	12/2012
WO	99/06759	A1	2/1999
WO	99/10867	A1	3/1999
WO	99/31560	A2	6/1999
WO	99/45312	A1	9/1999
WO	99/57945	A1	11/1999
WO	00/01067	A2	1/2000

Decision in *Altair Engineering, Inc. v. LEDdynamics* (Fed. Cir. Mar. 9, 2011).

Web page at http://trucklite.com/leds_14.htm printed on Jan. 13, 2000.

Web page at http://trucklite.com/leds_2.htm printed on Jan. 13, 2000.

Web page at http://trucklite.com/leds_4.htm printed on Jan. 13, 2000.

Web page at http://www.telecite.com/en/products/options_en.htm printed on Jan. 13, 2000.

Web page at <http://www.dialight.com/trans.htm> printed on Jan. 13, 2000.

Web page at <http://www.ledlight.com/replac.htm> printed on Jan. 13, 2000.

LEDTRONICS, apparently 1996 Catalog, apparently cover page and p. 10.

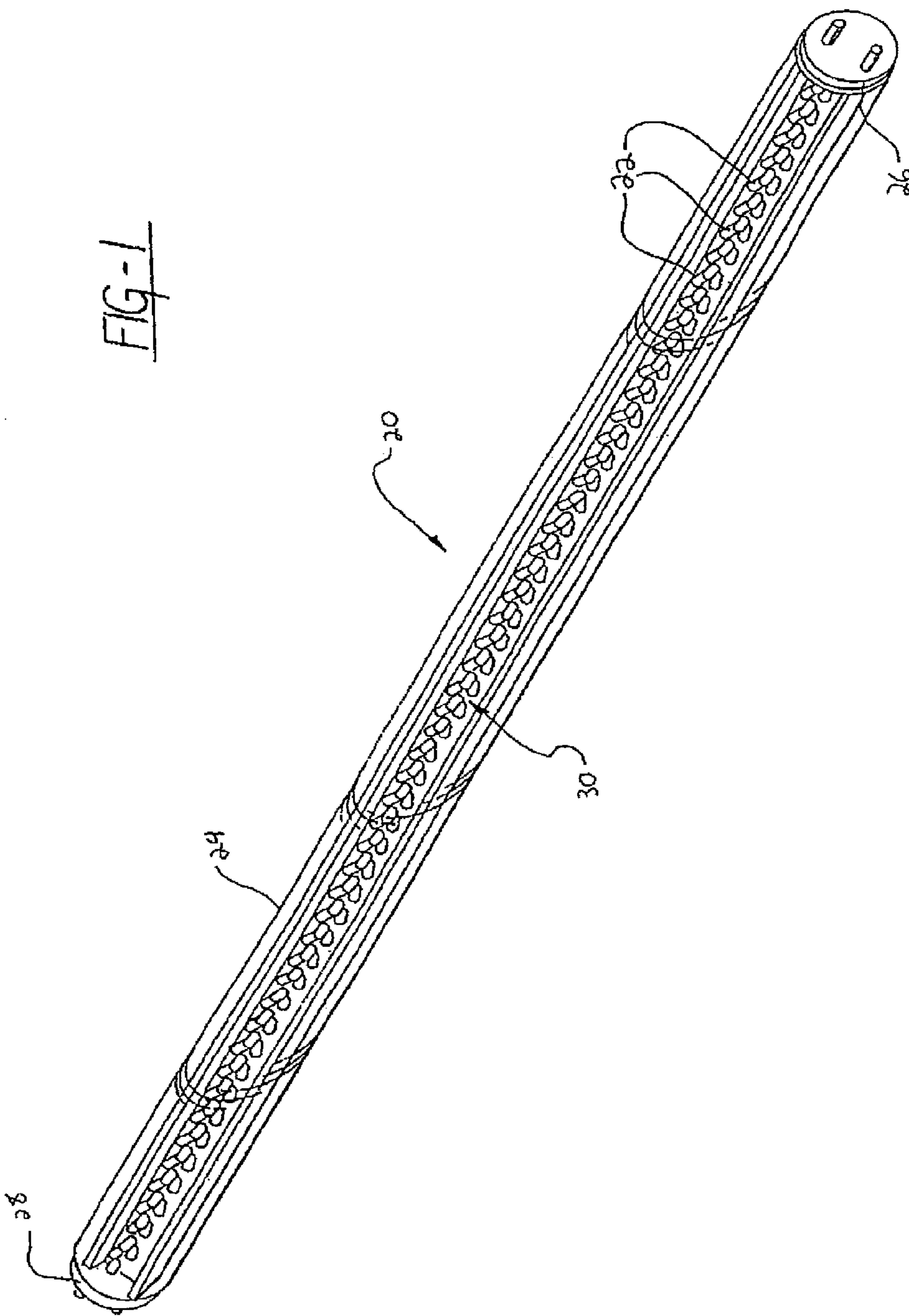
Petition for Inter Partes Review of U.S. Pat. No. 8,093,823, IPR # 2014-00448 filed Feb. 19, 2014 in 1175 pages. (uploaded in three parts due to EFS size limits).

Petition for Inter Partes Review of U.S. Pat. No. 7,510,299, IPR # 2014-00710 filed Apr. 30, 2014 in 2135 pages. (uploaded in ten parts due to EFS size limits).

Claim charts submitted in initial invalidity contentions served on May 8, 2014 in Civil Case No. 2:13-cv-14961 (E.D. Mich.) in 174 pages.

Lighting Handbook, 8th Edition, Illuminating Engineering Society of North America, 1993, pp. 237-240.

* cited by examiner



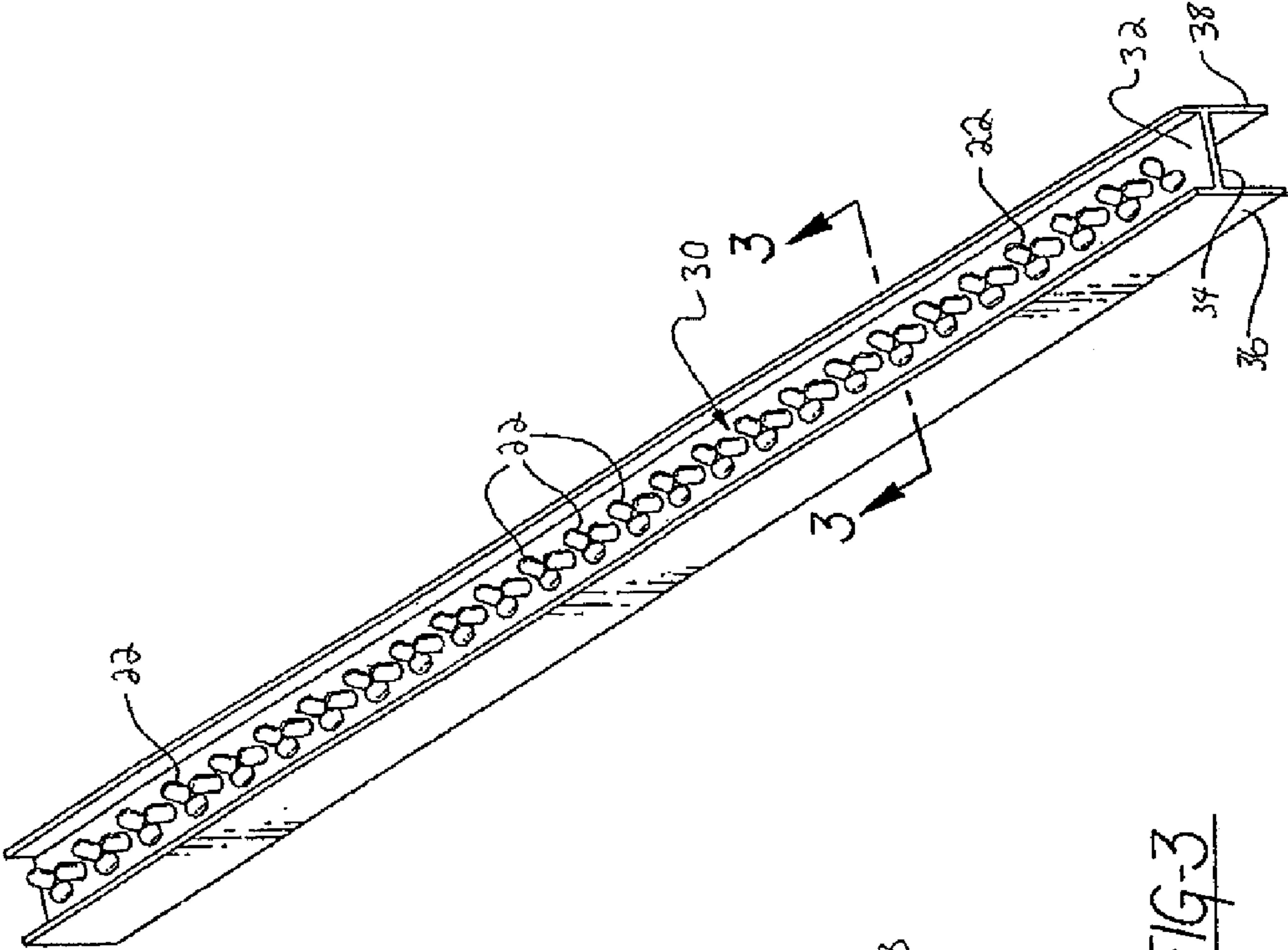


FIG-2

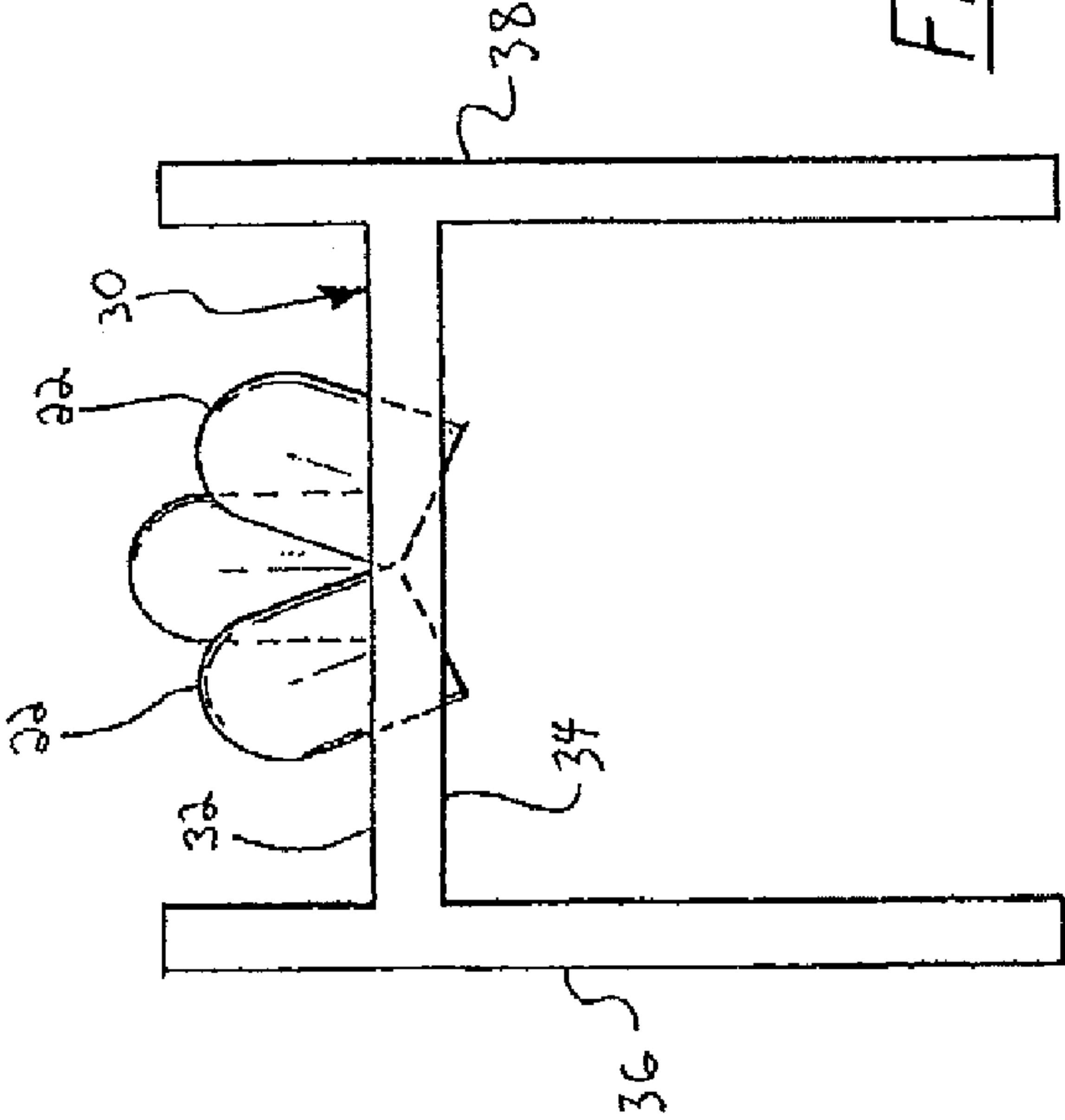


FIG-3

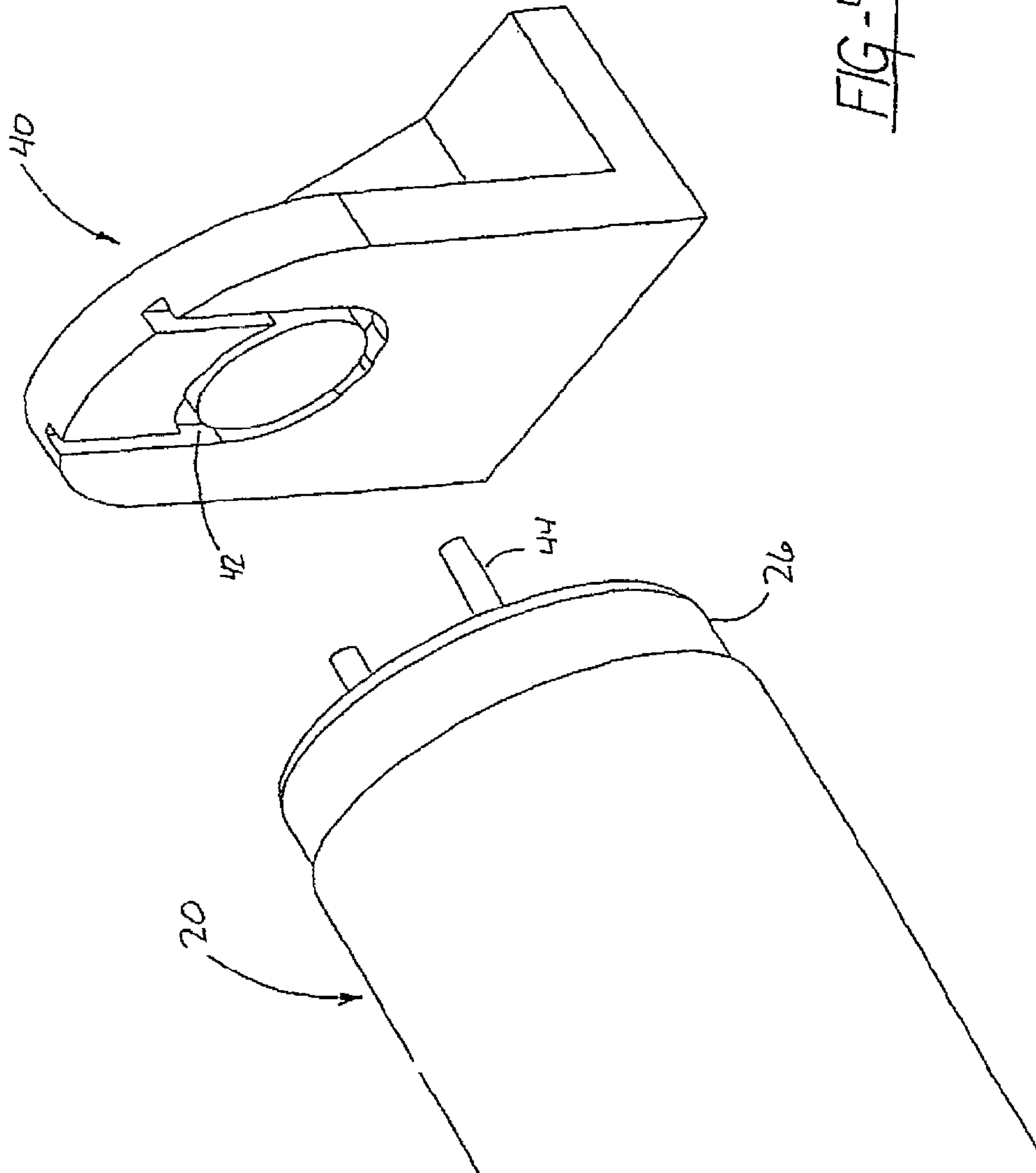


FIG-4

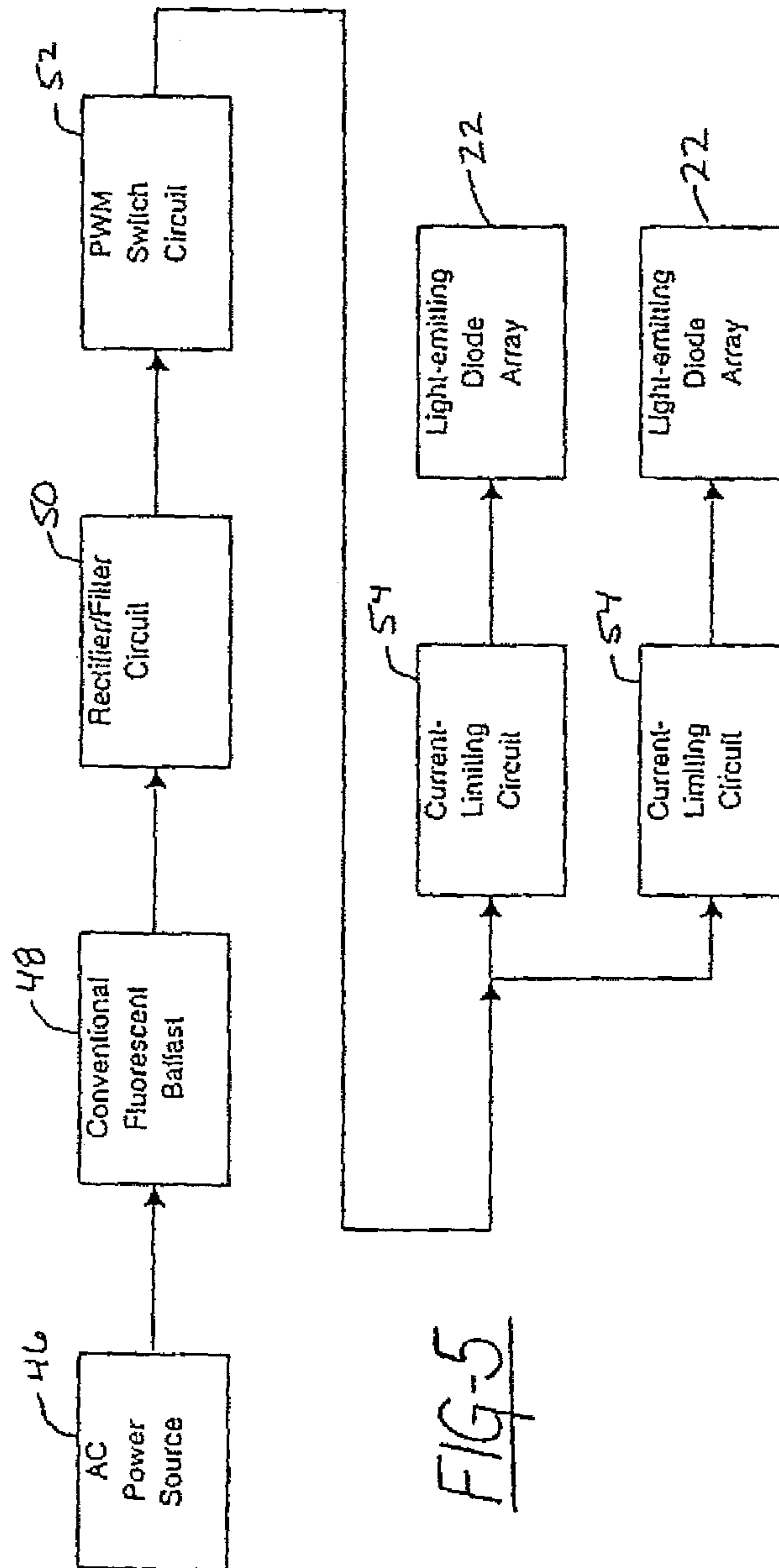
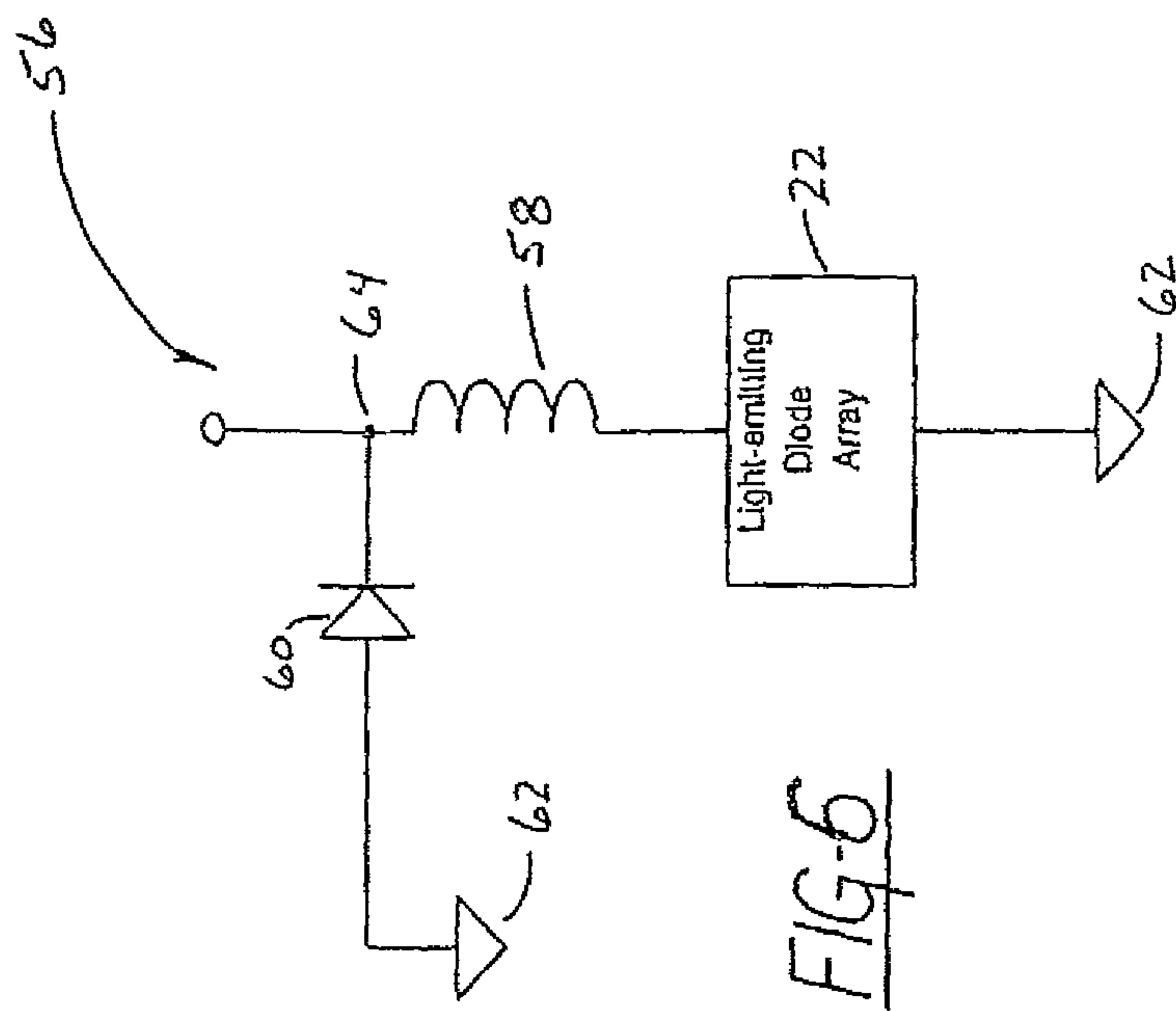


FIG-5



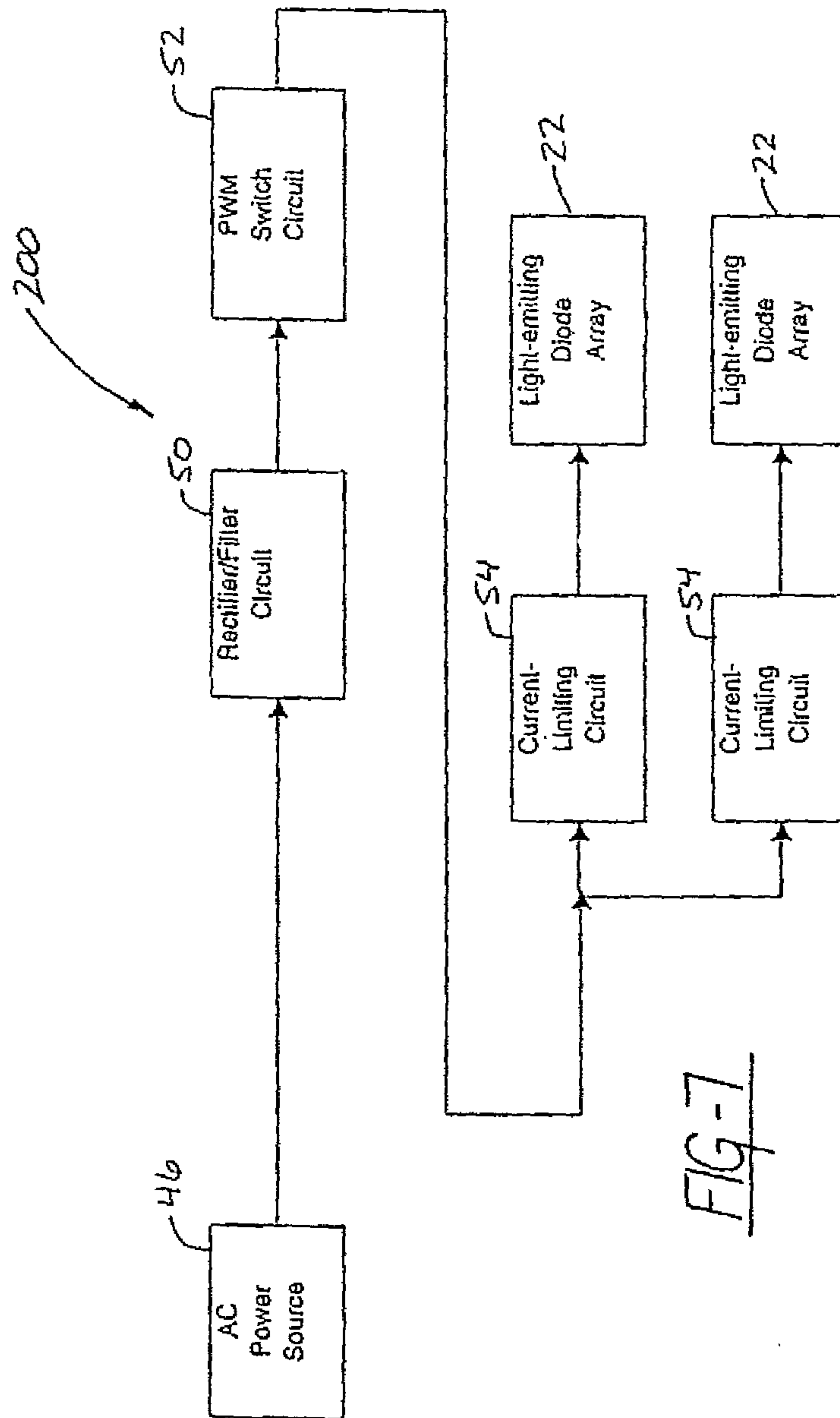
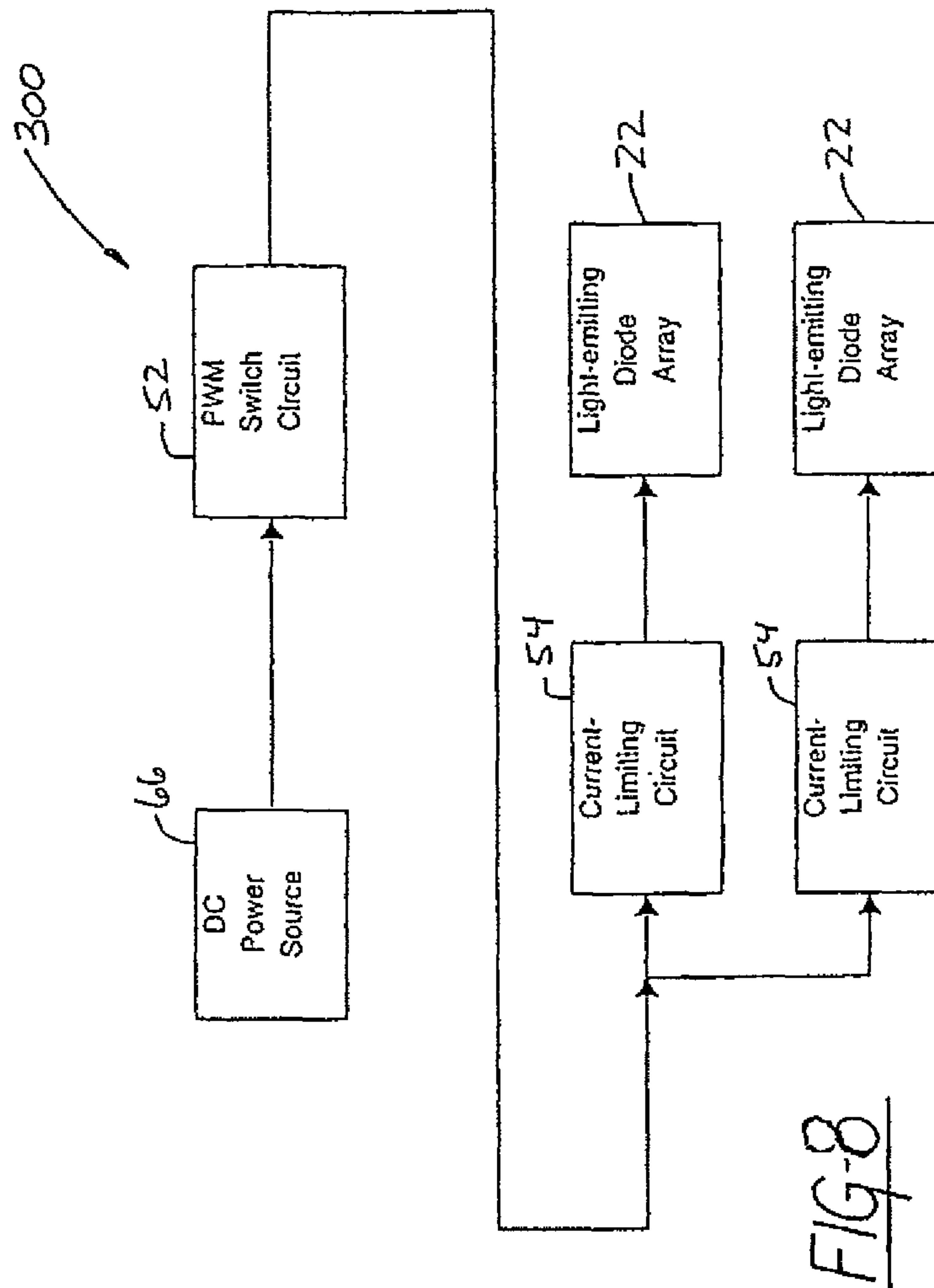


FIG-7



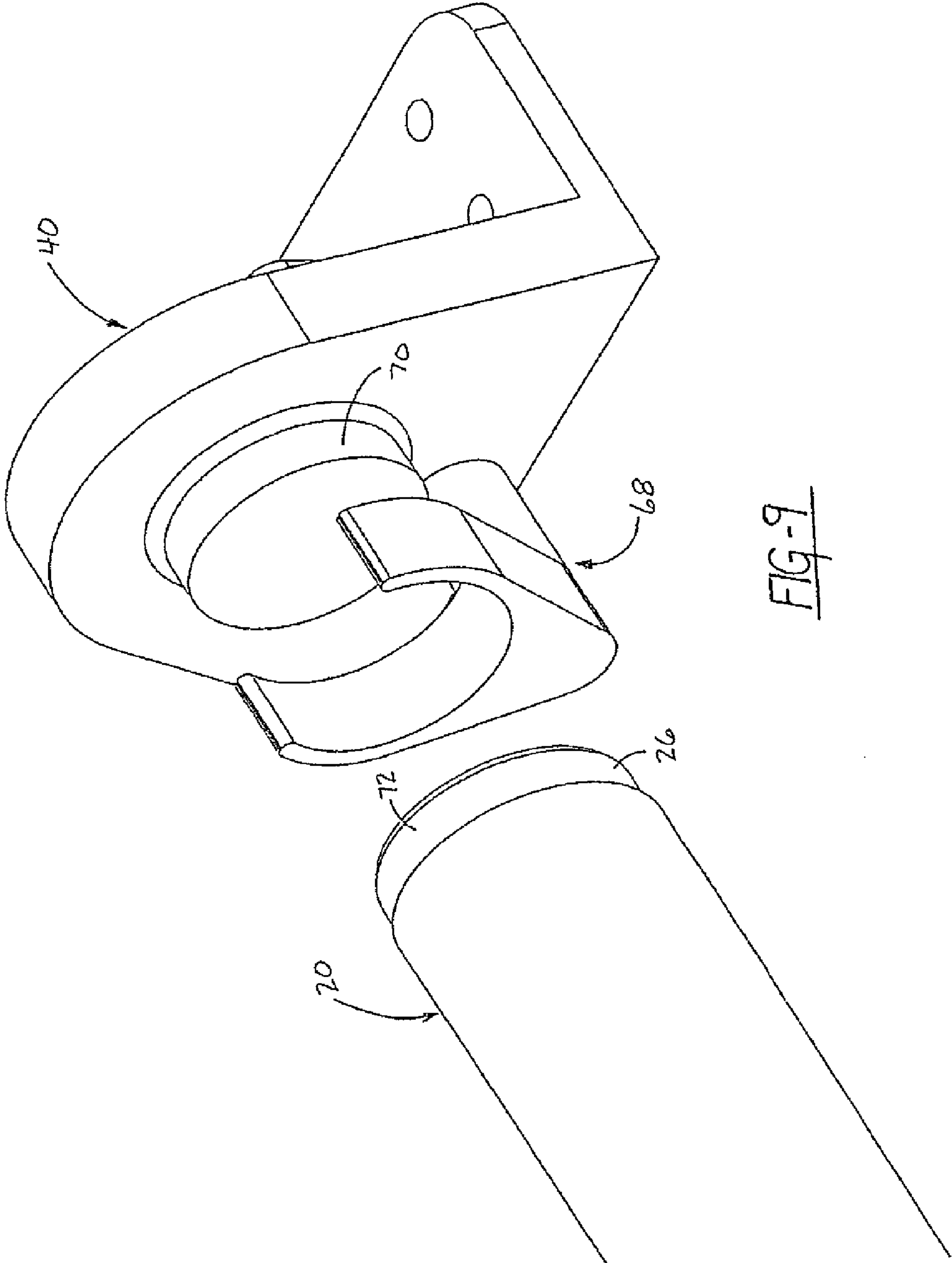


FIG-9

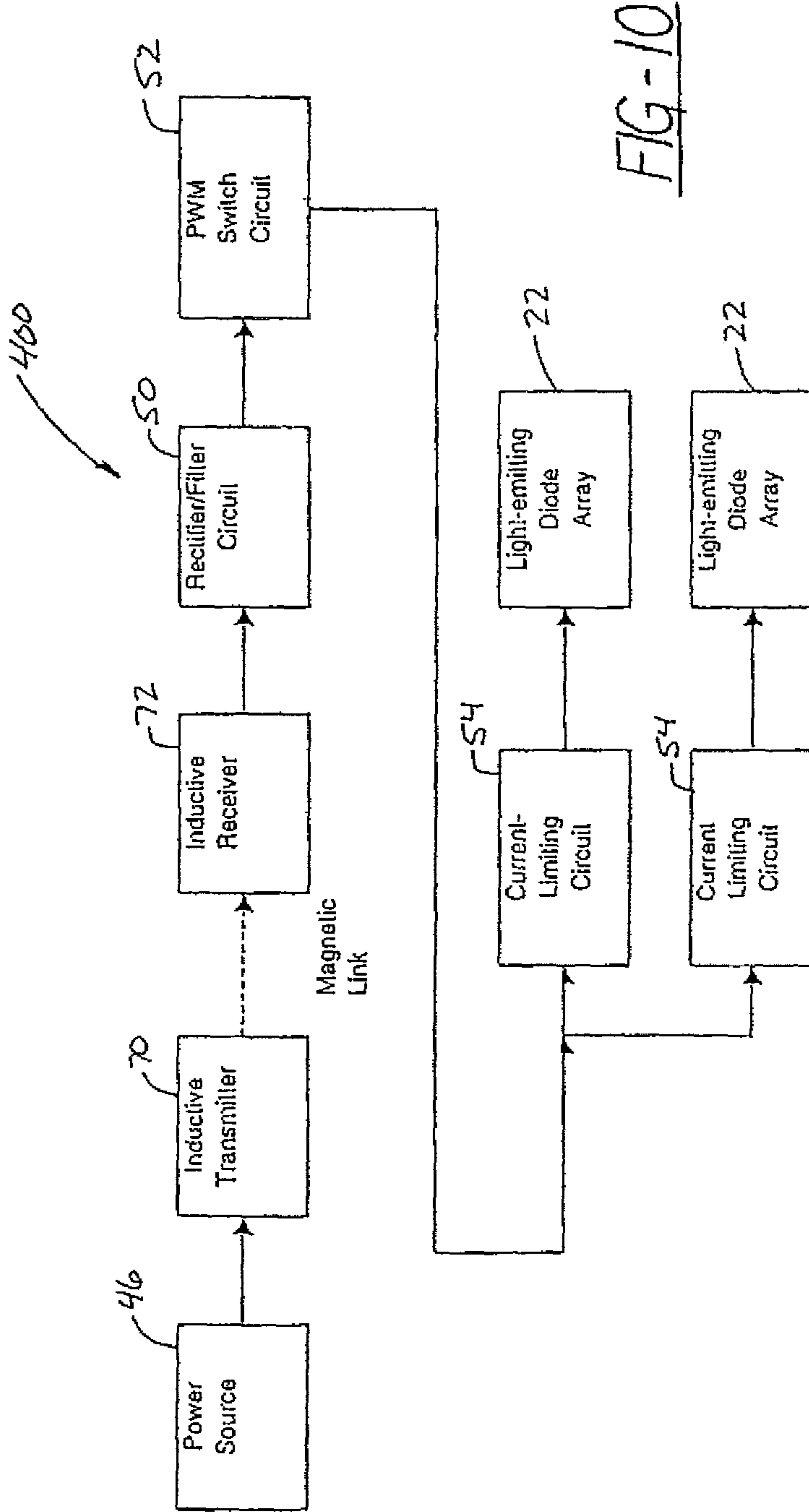


FIG-10

LIGHT TUBE AND POWER SUPPLY CIRCUIT**CROSS-REFERENCE TO RELATED APPLICATIONS**

This application is a continuation of U.S. patent application Ser. No. 14/299,909 and U.S. patent application Ser. No. 14/299,915, both filed Jun. 9, 2014, which are continuations of U.S. patent application Ser. No. 13/777,331, filed Feb. 26, 2013 and issued as U.S. Pat. No. 8,866,396 on Oct. 21, 2014, which is a continuation of U.S. patent application Ser. No. 12/965,019, filed Dec. 10, 2010 and issued as U.S. Pat. No. 8,382,327 on Feb. 26, 2013, which is a continuation of U.S. patent application Ser. No. 11/085,744, filed Mar. 21, 2005 and issued as U.S. Pat. No. 8,247,985 on Aug. 21, 2012, which is a continuation of U.S. patent application Ser. No. 09/782,375, filed Feb. 12, 2001 and issued as U.S. Pat. No. 7,049,761 on May 23, 2006, which claims the benefit of U.S. Provisional Application No. 60/181,744 filed Feb. 11, 2000.

FIELD OF THE INVENTION

The present invention relates to a light tube illuminated by LEDs (light emitting diodes) which are packaged inside the light tube and powered by a power supply circuit.

BACKGROUND OF THE INVENTION

Conventional fluorescent lighting systems include fluorescent light tubes and ballasts. Such lighting systems are used in a variety of locations, such as buildings and transit buses, for a variety of lighting purposes, such as area lighting or back-lighting. Although conventional fluorescent lighting systems have some advantages over known lighting options, such as incandescent lighting systems, conventional fluorescent light tubes and ballasts have several shortcomings. Conventional fluorescent light tubes have a short life expectancy, are prone to fail when subjected to excessive vibration, consume high amounts of power, require a high operating voltage, and include several electrical connections which reduce reliability. Conventional ballasts are highly prone to fail when subjected to excessive vibration. Accordingly, there is a desire to provide a light tube and power supply circuit which overcome the shortcomings of conventional fluorescent lighting systems. That is, there is a desire to provide a light tube and power supply circuit which have a long life expectancy, are resistant to vibration failure, consume low amounts of power, operate on a low voltage, and are highly reliable. It would also be desirable for such a light tube to mount within a conventional fluorescent light tube socket.

SUMMARY OF THE INVENTION

Embodiments of a replacement light tube for replacing a fluorescent light tube are disclosed herein. In one embodiment, the replacement light tube includes an elongate tubular housing having a first end and a second end and a first end cap and a second end cap disposed on the first end and the second end, respectively, each configured to fit with a socket for the fluorescent light tube. The replacement light tube also includes a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first end and the second end and having spaced-apart sidewalls extending away from the first surface and extending within the elongate tubular housing between the first end and the second end. At least a portion of the sidewalls are in contact with an interior surface of the elongate tubular housing.

Further, the replacement light tube includes a plurality of white light emitting diodes supported only by a second surface of the planar portion opposite to the first surface and between the first end and the second end. The plurality of light emitting diodes are arranged to emit light through the elongate tubular housing.

In another embodiment, the replacement light tube includes an elongate tubular housing having a first end and a second end and a first end cap and a second end cap disposed on the first end and the second end, respectively, each configured to fit with a socket for the fluorescent light tube and comprising a respective pair of electrical bi-pin connectors. The replacement light tube also includes a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first end and the second end and having spaced-apart sidewalls extending away from the first surface and extending within the elongate tubular housing between the first end and the second end. At least a portion of the sidewalls are in contact with an interior surface of the elongate tubular housing. Further, the replacement light tube includes a plurality of white light emitting diodes supported only by a second surface of the planar portion opposite to the first surface and between the first end and the second end. The plurality of light emitting diodes are arranged to emit light through the elongate tubular housing. The support structure divides the elongate tubular housing into a first space in which the plurality of light emitting diodes are housed and a second space defined by the planar portion, the sidewalls and the interior surface of the elongate tubular housing.

In another embodiment, the replacement light tube includes an elongate tubular housing having a first end and a second end, and a first end cap and a second end cap disposed on the first end and the second end, respectively, each configured to fit with a socket for the fluorescent light tube. The replacement light tube also includes a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first end and the second end and having spaced-apart sidewalls extending away from the first surface and extending within the elongate tubular housing between the first end and the second end. At least a portion of the sidewalls are in contact with an interior surface of the elongate tubular housing. Further, the replacement light tube includes a plurality of white light emitting diodes supported by the first surface between the first end and the second end. The plurality of light emitting diodes are arranged to emit light through the elongate tubular housing. The replacement light tube further includes a power supply circuit including a pulse width modulator and a current limiter. The power supply circuit is packaged within one of the end caps.

In another embodiment, the replacement light tube includes an elongate tubular housing having a first end and a second end and a first end cap and a second end cap disposed on the first end and the second end, respectively, each configured to fit with a socket for the fluorescent light tube. The replacement light tube also includes a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first end and the second end and having spaced-apart sidewalls extending away from the planar portion and extending within the elongate tubular housing between the first end and the second end. At least a portion of the sidewalls are in contact with an interior surface of the elongate tubular housing. The planar portion is integral with the sidewalls. Further, the replacement light tube includes a plurality of white light emitting diodes supported by the first surface between the first end and the

3

second end. The plurality of light emitting diodes are arranged to emit light through the elongate tubular housing. The replacement light tube further includes a power supply circuit including a pulse width modulator and a current limiter. At least a portion of the power supply circuit is packaged within the elongate tubular housing or one of the end caps.

These and other embodiments will be discussed in additional detail hereafter.

BRIEF DESCRIPTION OF THE DRAWINGS

The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views, and wherein:

FIG. 1 is a line drawing showing a light tube, in perspective view, which in accordance with the present invention is illuminated by LEDs packaged inside the light tube;

FIG. 2 is a perspective view of the LEDs mounted on a circuit board;

FIG. 3 is a cross-sectional view of FIG. 2 taken along lines 3-3;

FIG. 4 is a fragmentary, perspective view of one embodiment of the present invention showing one end of the light tube disconnected from one end of a light tube socket;

FIG. 5 is an electrical block diagram of a first power supply circuit for supplying power to the light tube;

FIG. 6 is an electrical schematic of a switching power supply type current limiter;

FIG. 7 is an electrical block diagram of a second power supply circuit for supplying power to the light tube;

FIG. 8 is an electrical block diagram of a third power supply circuit for supplying power to the light tube;

FIG. 9 is a fragmentary, perspective view of another embodiment of the present invention showing one end of the light tube disconnected from one end of the light tube socket; and

FIG. 10 is an electrical block diagram of a fourth power supply circuit for supplying power to the light tube.

DETAILED DESCRIPTION

FIG. 1 is a line drawing showing a light tube 20 in perspective view. In accordance with the present invention, the light tube 20 is illuminated by LEDs 22 packaged inside the light tube 20. The light tube 20 includes a cylindrically shaped bulb portion 24 having a pair of end caps 26 and 28 disposed at opposite ends of the bulb portion. Preferably, the bulb portion 24 is made from a transparent or translucent material such as glass, plastic, or the like. As such, the bulb material may be either clear or frosted.

In a preferred embodiment of the present invention, the light tube 20 has the same dimensions and end caps 26 and 28 (e.g. electrical male bi-pin connectors, type G13) as a conventional fluorescent light tube. As such, the present invention can be mounted in a conventional fluorescent light tube socket.

The line drawing of FIG. 1 also reveals the internal components of the light tube 20. The light tube 20 further includes a circuit board 30 with the LEDs 22 mounted thereon. The circuit board 30 and LEDs 22 are enclosed inside the bulb portion 24 and the end caps 26 and 28.

FIG. 2 is a perspective view of the LEDs 22 mounted on the circuit board 30. A group of LEDs 22, as shown in FIG. 2, is commonly referred to as a bank or array of LEDs. Within the scope of the present invention, the light tube 20 may include one or more banks or arrays of LEDs 22 mounted on one or more circuit boards 30. In a preferred embodiment of the

4

present invention, the LEDs 22 emit white light and, thus, are commonly referred to in the art as white LEDs. In FIGS. 1 and 2, the LEDs 22 are mounted to one surface 32 of the circuit board 30. In a preferred embodiment of the present invention, the LEDs 22 are arranged to emit or shine white light through only one side of the bulb portion 24, thus directing the white light to a predetermined point of use. This arrangement reduces light losses due to imperfect reflection in a conventional lighting fixture. In alternative embodiments of the present invention, LEDs 22 may also be mounted, in any combination, to the other surfaces 34, 36, and/or 38 of the circuit board 30.

FIG. 3 is a cross-sectional view of FIG. 2 taken along lines 3-3. To provide structural strength along the length of the light tube 20, the circuit board 30 is designed with a H-shaped cross-section. To produce a predetermined radiation pattern or dispersion of light from the light tube 20, each LED 22 is mounted at an angle relative to adjacent LEDs and/or the mounting surface 32. The total radiation pattern of light from the light tube 20 is effected by (1) the mounting angle of the LEDs 22 and (2) the radiation pattern of light from each LED. Currently, white LEDs having a viewing range between 6° and 45° are commercially available.

FIG. 4 is a fragmentary, perspective view of one embodiment of the present invention showing one end of the light tube 20 disconnected from one end of a light tube socket 40. Similar to conventional fluorescent lighting systems and in this embodiment of the present invention, the light tube socket 40 includes a pair of electrical female connectors 42 and the light tube 20 includes a pair of mating electrical male connectors 44.

Within the scope of the present invention, the light tube 20 may be powered by one of four power supply circuits 100, 200, 300, and 400. A first power supply circuit includes a power source and a conventional fluorescent ballast. A second power supply circuit includes a power source and a rectifier/filter circuit. A third power supply circuit includes a DC power source and a PWM (Pulse Width Modulation) circuit. A fourth power supply circuit powers the light tube 20 inductively.

FIG. 5 is an electrical block diagram of a first power supply circuit 100 for supplying power to the light tube 20. The first power supply circuit 100 is particularly adapted to operate within an existing, conventional fluorescent lighting system. As such, the first power supply circuit 100 includes a conventional fluorescent light tube socket 40 having two electrical female connectors 42 disposed at opposite ends of the socket. Accordingly, a light tube 20 particularly adapted for use with the first power supply circuit 100 includes two end caps 26 and 28, each end cap having the form of an electrical male connector 44 which mates with a corresponding electrical female connector 42 in the socket 40.

The first power supply circuit 100 also includes a power source 46 and a conventional magnetic or electronic fluorescent ballast 48. The power source 46 supplies power to the conventional fluorescent ballast 48.

The first power supply circuit 100 further includes a rectifier/filter circuit 50, a PWM circuit 52, and one or more current-limiting circuits 54. The rectifier/filter circuit 50, the PWM circuit 52, and the one or more current-limiting circuits 54 of the first power supply circuit 100 are packaged inside one of the two end caps 26 or 28 of the light tube 20.

The rectifier/filter circuit 50 receives AC power from the ballast 48 and converts the AC power to DC power. The PWM circuit 52 receives the DC power from the rectifier/filter circuit 50 and pulse-width modulates the DC power to the one or more current-limiting circuits 54. In a preferred embodiment

5

of the present invention, the PWM circuit **52** receives the DC power from the rectifier/filter circuit **50** and cyclically switches the DC power on and off to the one or more current-limiting circuits **54**. The DC power is switched on and off by the PWM circuit **52** at a frequency which causes the white light emitted from the LEDs **22** to appear, when viewed with a “naked” human eye, to shine continuously. The PWM duty cycle can be adjusted or varied by control circuitry (not shown) to maintain the power consumption of the LEDs **22** at safe levels.

The DC power is modulated for several reasons. First, the DC power is modulated to adjust the brightness or intensity of the white light emitted from the LEDs **22** and, in turn, adjust the brightness or intensity of the white light emitted from the light tube **20**. Optionally, the brightness or intensity of the white light emitted from the light tube **20** may be adjusted by a user. Second, the DC power is modulated to improve the illumination efficiency of the light tube **20** by capitalizing upon a phenomenon in which short pulses of light at high brightness or intensity to appear brighter than a continuous, lower brightness or intensity of light having the same average power. Third, the DC power is modulated to regulate the intensity of light emitted from the light tube **20** to compensate for supply voltage fluctuations, ambient temperature changes, and other such factors that affect the intensity of white light emitted by the LEDs **22**. Fourth, the DC power is modulated to raise the variations of the frequency of light above the nominal variation of 120 to 100 Hz thereby reducing illumination artifacts caused by low frequency light variations, including interactions with video screens. Fifth, the DC power may optionally be modulated to provide an alarm function wherein light from the light tube **20** cyclically flashes on and off.

The one or more current-limiting circuits **54** receive the pulse-width modulated or switched DC power from the PWM circuit **52** and transmit a regulated amount of power to one or more arrays of LEDs **22**. Each current-limiting circuit **54** powers a bank of one or more white LEDs **22**. If a bank of LEDs **22** consists of more than one LED, the LEDs are electrically connected in series in an anode to cathode arrangement. If brightness or intensity variation between the LEDs **22** can be tolerated, the LEDs can be electrically connected in parallel.

The one or more current-limiting circuits **54** may include (1) a resistor, (2) a current-limiting semiconductor circuit, or (3) a switching power supply type current limiter.

FIG. **6** is an electrical schematic of a switching power supply type current limiter **56**. The limiter **56** includes an inductor **58**, electrically connected in series between the PWM circuit **52** and the array of LEDs **22**, and a power diode **60**, electrically connected between ground **62** and a PWM circuit/inductor node **64**. The diode **60** is designed to begin conduction after the PWM circuit **52** is switched off. In this case, the value of the inductor **58** is adjusted in conjunction with the PWM duty cycle to provide the benefits described above. The switching power supply type current limiter **56** provides higher power efficiency than the other types of current-limiting circuits listed above.

FIG. **7** is an electrical block diagram of a second power supply circuit **200** for supplying power to the light tube **20**. Similar to the first power supply circuit **100**, the second power supply circuit **200** includes a conventional fluorescent light tube socket **40** having two electrical female connectors **42** disposed at opposite ends of the socket **40**. Accordingly, a light tube **20** particularly adapted for use with the second power supply circuit **200** includes two end caps **26** and **28**,

6

each end cap having the form of an electrical male connector **44** which mates with a corresponding electrical female connector **42** in the socket **40**.

In the second power supply circuit **200**, the power source **46** supplies power directly to the rectifier/filter circuit **50**. The rectifier/filter circuit **50**, the PWM circuit **52**, and the one or more current-limiting circuits **54** operate as described above to power the one or more arrays of LEDs **22**. The rectifier/filter circuit **50**, the PWM circuit **52**, and the one or more current-limiting circuits **54** of the second power supply circuit **200** are preferably packaged inside the end caps **26** and **28** or the bulb portion **24** of the light tube **20** or inside the light tube socket **40**.

FIG. **8** is an electrical block diagram of a third power supply circuit **300** for supplying power to the light tube **20**. Similar to the first and second power supply circuits **100** and **200**, the third power supply circuit **300** includes a conventional fluorescent light tube socket **40** having two electrical female connectors **42** disposed at opposite ends of the socket **40**. Accordingly, a light tube **20** particularly adapted for use with the third power supply circuit **300** includes two end caps **26** and **28**, each end cap having the form of an electrical male connector **44** which mates with a corresponding electrical female connector **42** in the socket **40**.

The third power supply circuit **300** includes a DC power source **66**, such as a vehicle battery. In the third power supply circuit **300**, the DC power source **66** supplies DC power directly to the PWM circuit **52**. The PWM circuit **52** and the one or more current-limiting circuits **54** operate as described above to power the one or more arrays of LEDs **22**. In the third power supply circuit **300**, the PWM circuit **52** is preferably packaged in physical location typically occupied by the ballast of a conventional fluorescent lighting system while the one or more current-limiting circuits **54** and LEDs **22** are preferably packaged inside the light tube **20**, in either one of the two end caps **26** or **28** or the bulb portion **24**.

FIG. **9** is a fragmentary, perspective view of another embodiment of the present invention showing one end of the light tube **20** disconnected from one end of the light tube socket **40**. In this embodiment of the present invention, the light tube socket **40** includes a pair of brackets **68** and the light tube **20** includes a pair of end caps **26** and **28** which mate with the brackets **68**.

FIG. **10** is an electrical block diagram of a fourth power supply circuit **400** for supplying power to the light tube **20**. Unlike the first, second, and third power supply circuits **100**, **200**, and **300** which are powered through direct electrical male and female connectors **44** and **42**, the fourth power supply circuit **400** is powered inductively. As such, the fourth power supply circuit **400** includes a light tube socket **40** having two brackets **68** disposed at opposite ends of the socket **40**. At least one bracket **68** includes an inductive transmitter **70**. Accordingly, a light tube **20** particularly adapted for use with the fourth power supply circuit **400** has two end caps **26** and **28** with at least one end cap including an inductive receiver or antenna **72**. When the light tube **20** is mounted in the light tube socket **40**, the at least one inductive receiver **72** in the light tube **20** is disposed adjacent to the at least one inductive transmitter **70** in the light tube socket **40**.

The fourth power supply circuit **400** includes the power source **46** which supplies power to the at least one inductive transmitter **70** in the light tube socket **40**. The at least one transmitter **70** inductively supplies power to the at least one receiver **72** in one of the end caps **26** and/or **28** of the light tube **20**. The at least one inductive receiver **72** supplies power to the rectifier/filter circuit **50**. The rectifier/filter circuit **50**, PWM circuit **52**, and the one or more current-limiting circuits

54 operate as described above to power the one or more arrays of LEDs 22. In this manner, the light tube 20 is powered without direct electrical connection.

What is claimed is:

1. A replacement light tube for replacing a fluorescent light tube, comprising:

an elongate tubular housing having a first end and a second end;

a first end cap and a second end cap disposed on the first end and the second end, respectively, each configured to fit with a socket for the fluorescent light tube;

a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first end and the second end and having spaced-apart sidewalls extending away from the first surface and extending within the elongate tubular housing between the first end and the second end, at least a portion of the sidewalls in contact with an interior surface of the elongate tubular housing; and

a plurality of white light emitting diodes supported by a second surface of the planar portion opposite to the first surface and between the first end and the second end, the plurality of white light emitting diodes arranged to emit light through the elongate tubular housing.

2. The replacement light tube of claim 1, wherein the sidewalls each have an outside surface facing the interior surface of the elongate housing and an inside surface opposite the outside surface and a substantially uniform cross-section along a length of the elongate tubular housing.

3. The replacement light tube of claim 2, wherein the planar portion is integral with the sidewalls, and the sidewalls are generally perpendicular to the planar portion.

4. The replacement light tube of claim 1, wherein the rigid support structure has a substantially uniform cross-section along a length of the elongate tubular housing.

5. The replacement light tube of claim 1, wherein the first surface extends in a plane within the elongate tubular housing, and wherein the sidewalls contact the interior surface of the elongate tubular housing away from the plane in which the first surface extends, the sidewalls being free from white light emitting diodes.

6. The replacement light tube of claim 1, wherein the planar portion, the sidewalls and the interior surface of the elongate tubular housing form a space extending between the first end and the second end.

7. The replacement light tube of claim 1, wherein the support structure divides the elongate tubular housing into a first space in which the plurality of light emitting diodes are housed and a second space defined by the planar portion, the sidewalls and the interior surface of the elongate tubular housing.

8. The replacement light tube of claim 1, further comprising:

a power supply circuit configured to provide power to the plurality of light emitting diodes, at least a portion of the power supply circuit packaged inside the elongate tubular housing.

9. The replacement light tube of claim 8, wherein the power supply circuit comprises a pulse width modulator and a current limiter, the current limiter configured to receive power from the pulse width modulator and configured to transmit power to at least some of the plurality of light emitting diodes.

10. The replacement light tube of claim 9, wherein the current limiter comprises an inductive element electrically coupled between the pulse width modulator and the at least some of the plurality of light emitting diodes.

11. The replacement light tube of claim 9, wherein the current limiter and the pulse width modulator are packaged outside of the elongate tubular housing.

12. The replacement light tube of claim 9, wherein the pulse width modulator is configured to receive power from a power source and configured to regulate the intensity of light emitted from the plurality of light emitting diodes by cyclically switching the received power on and off according to a varying duty cycle.

13. The replacement light tube of claim 8, wherein the power supply circuit includes a rectifier configured to receive alternating current (AC) input and to provide direct current (DC) output.

14. The replacement light tube of claim 13, wherein the rectifier is arranged to provide the DC output to the pulse width modulator.

15. The replacement light tube of claim 8, wherein the power supply circuit includes a pulse width modulator that switches direct current (DC) power to the plurality of light emitting diodes on and off at a frequency such that the light emitted from the plurality of light emitting diodes appears, when viewed by a human eye, to shine continuously.

16. The replacement light tube of claim 1, wherein the plurality of light emitting diodes is arranged in spaced-apart banks of light emitting diodes such that a spacing between light emitting diodes in each bank is less than a spacing between centers of adjacent banks, each of the spaced-apart banks including more than one light emitting diode.

17. The replacement light tube of claim 1, wherein the first end cap and the second end cap comprise a respective pair of electrical bi-pin connectors.

18. The replacement light tube of claim 1, wherein the light emitting diodes are arranged as a plurality of groups spaced along an axis extending between the first end and second end, each group comprising light emitting diodes spatially displaced from each other in a direction orthogonal to the axis.

19. A replacement light tube for replacing a fluorescent light tube, comprising:

an elongate tubular housing having a first end and a second end;

a first end cap and a second end cap disposed on the first end and the second end, respectively, each configured to fit with a socket for the fluorescent light tube and comprising a respective pair of electrical bi-pin connectors;

a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first end and the second end and having spaced-apart sidewalls extending away from the first surface and extending within the elongate tubular housing between the first end and the second end, at least a portion of the sidewalls in contact with an interior surface of the elongate tubular housing; and

a plurality of white light emitting diodes supported by a second surface of the planar portion opposite to the first surface and between the first end and the second end, the plurality of white light emitting diodes arranged to emit light through the elongate tubular housing; wherein the support structure divides the elongate tubular housing into a first space in which the plurality of white light emitting diodes are housed and a second space defined by the planar portion, the sidewalls and the interior surface of the elongate tubular housing.

20. The replacement light tube of claim 19, further comprising:

a power supply circuit including a pulse width modulator and a current limiter, the current limiter configured to receive power from the pulse width modulator and to

9

transmit power to at least some of the plurality of light emitting diodes, at least a portion of the power supply circuit packaged inside the elongate tubular housing.

21. The replacement light tube of claim 20, wherein the current limiter comprises an inductive element electrically coupled between the pulse width modulator and the at least some of the plurality of light emitting diodes.

22. The replacement light tube of claim 20, wherein the current limiter and the pulse width modulator are packaged outside of the elongate tubular housing.

23. The replacement light tube of claim 20, wherein the power supply circuit includes a rectifier configured to receive alternating current (AC) input and to provide direct current (DC) output.

24. A replacement light tube for replacing a fluorescent light tube, comprising:

an elongate tubular housing having a first end and a second end;

a first end cap and a second end cap disposed on the first end and the second end, respectively, each configured to fit with a socket for the fluorescent light tube;

a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first end and the second end and having spaced-apart sidewalls extending away from the first surface and extending within the elongate tubular housing between the first end and the second end, at least a portion of the sidewalls in contact with an interior surface of the elongate tubular housing;

a plurality of white light emitting diodes supported by the first surface between the first end and the second end, the plurality of white light emitting diodes arranged to emit light through the elongate tubular housing; and

a power supply circuit including a pulse width modulator and a current limiter, the power supply circuit being packaged within one of the end caps.

25. The replacement light tube of claim 24 wherein the rigid support structure has a substantially uniform cross-section along a length of the elongate tubular housing.

10

26. The replacement light tube of claim 24 wherein the first surface extends in a plane within the elongate tubular housing and wherein the sidewalls extend sufficiently far from the plane such that light emitted by the light emitting diodes is confined to an included angle of less than 180° by the sidewalls.

27. A replacement light tube for replacing a fluorescent light tube, comprising:

an elongate tubular housing having a first end and a second end;

a first end cap and a second end cap disposed on the first end and the second end, respectively, each configured to fit with a socket for the fluorescent light tube;

a rigid support structure having a planar portion having a first surface extending within the elongate tubular housing between the first end and the second end and having spaced-apart sidewalls extending away from the planar portion and extending within the elongate tubular housing between the first end and the second end, at least a portion of the sidewalls in contact with an interior surface of the elongate tubular housing, the planar portion being integral with the sidewalls;

a plurality of white light emitting diodes supported by the first surface between the first end and the second end, the plurality of white light emitting diodes arranged to emit light through the elongate tubular housing; and

a power supply circuit including a pulse width modulator and a current limiter, at least a portion of the power supply circuit being packaged within the elongate tubular housing or one of the end caps.

28. The replacement light tube of claim 27, wherein the sidewalls extend from the first surface.

29. The replacement light tube of claim 27, wherein the sidewalls extend from a second surface of the planar portion, the second surface being opposite the first surface.

30. The replacement light tube of claim 27, wherein a portion of the power supply circuit is external to the elongate tubular housing and the first and second end caps.

* * * * *